

would heat up quickly. The start-up heater may be powered by any suitable means. Typically, a small electric heater is used. The energy may be supplied by a small battery.

## EXAMPLES

### **EXAMPLE 1. Production of separator plates coated with a Pd catalyst on a zirconia support.**

[0066] A Pd-impregnated zirconia sol was prepared following the procedure taught in US Patent 5,259,754, Example 1, the disclosure of which is hereby incorporated by reference. An Fe/Cr/Al metal foil was oxidized in ambient air at 900°C for ten hours to form alumina whiskers on the foil surface. The colloidal Pd/ZrO<sub>2</sub> sol was sprayed onto both sides of the corrugated foil. The coated foil was then heat treated for ten hours in air at 700° C. The final foil contained 10 mg Pd/ZrO<sub>2</sub> /cm<sup>2</sup> foil surface, and this dual-surface catalytic foil is used to form separator plates in a reactor design of this invention.

### **EXAMPLE 2. Reactor operation.**

[0067] Two separator plates constructed of the foil prepared in accordance with the procedure of Example 1 were employed in a reactor of the design illustrated in **Fig. 7** (described above) and tested. Flow-directing devices illustrated in **Fig. 6** were inserted in the reforming and combustion channels. The air flow rate in the test was 100 SLPM; the fuel was natural gas supplied at a flow rate of 3 SLPM both on the combustion and reforming channels, the steam/methane molar ratio was 3.0, and the steady state preheat temperature for all inlet streams was 485°C. The performance of those plates is shown in **Fig.. 8**. Solid trace lines in this figure denote reformer zone inlet and outlet temperatures versus runtime. The Temperatures were measured in the

reforming channel at the upstream and downstream edges of the catalyst coating R (see positions 60 and 62, respectively, in Fig. 6). An overlay plot shows the conversion of methane versus runtime, the diamonds representing the conversion of methane to  $H_2$ , CO, and  $CO_2$ . After approximately three hours on stream, the system was at a steady state with reforming zone inlet temperature matching the preheat temperature of  $485^\circ C$  and outlet reforming zone temperature registering approximately  $740^\circ C$ . Methane conversion remained essentially constant in the range of about 74-78% for the 3 ½ hr. duration of the steady state portion of the test.

[0068] The temperatures in the reformer zone of the present bicatalytic plate reformer invention are much lower than those observed in conventional steam reforming processes. More significantly, they are also lower than those reported in prior art, non-catalytic plate reformers. For example, the reformer described in US Pat. No. 5,015,444 of Koga et al. operates with an inlet temperature of  $650^\circ C$  and an outlet temperature of  $850^\circ C$ . Those temperatures are over  $100^\circ C$  higher than the temperatures of operation of the catalytic reformer of the present invention. Low temperatures of operation result in longer catalyst life and decreased thermal losses.

### **EXAMPLE 3. Production of separator plates coated with a combustion catalyst on one side and a reforming catalyst on the opposite side.**

[0069] In this example, the combustion catalyst is a palladium catalyst on a zirconia support coated on one side of a foil separator plate as indicated in Example 1. The reforming catalyst is a rhodium catalyst on a zirconia-modified support coated on the other side of the same foil in process steps as follows:  $ZrO_2$  powder (modified by the addition of ceria and lanthana) was impregnated with a solution of  $RhCl_3$ . The final Rh loading was 5 wt%. The Rh-impregnated zirconia paste was dried at  $120^\circ C$  overnight. It was then heat treated at  $200^\circ C$  for 2 hrs followed by heat treatment in ambient air at  $500^\circ C$  for 4 hrs. This solid material was mixed with water acidified

with sulfuric acid to a pH of about 3, and ball milled in a polymer lined ball mill using a zirconia grinding media for ten hours. This colloidal Rh/ZrO<sub>2</sub> sol was diluted to a concentration of 15% ZrO<sub>2</sub> by weight with additional water. An Fe/Cr/Al metal foil was oxidized at 900°C. in air for ten hours to form alumina whiskers on the foil surface. The colloidal Pd/ZrO<sub>2</sub> sol was sprayed onto one side of the metal foil and dried. Then, the colloidal Rh/ZrO<sub>2</sub> sol was sprayed onto the opposite side of the metal foil and dried. The coated foil was then heat-treated at 700° C for ten hours in ambient air. The final foil contained 10 mg Rh/ZrO<sub>2</sub> /cm<sup>2</sup> on one face and 10 mg Pd/ZrO<sub>2</sub> on the opposite face.

#### **EXAMPLE 4. Reactor operation.**

[0070] Two bi-catalyst separator plates constructed from the foil prepared as in Example 3 were employed in a reactor of the design of **Fig. 7**, and tested. The air flow rate was 100 SLPM, the natural gas flow rate was 3 SLPM through both the combustion and reforming channel zones, and the steady state preheat temperature for all inlet streams was 500°C. The performance of the reformer reactor employing bicatalytic separator plates of the invention is shown in FIG. 9. This figure shows plots of reformer zone inlet and outlet temperatures (solid traces), and conversion of methane, versus runtime (diamonds). After approximately three hours on stream, temperatures were at a steady state with reforming zone inlet temperature matching the preheat temperature of 500°C, while outlet reforming zone temperature was approximately 740°C. Methane conversion was over 90% after 90 minutes on stream and essentially constant at 89-92% for the remaining 5+ hrs of the test. While we do not wish to be bound by theory, we believe that steady-state values for methane conversion were obtained before the reformer reached steady state temperatures because reforming reaction rates on the rhodium catalyst are high enough that the